CFD Analysis of Temperature Distribution and Relative Humidity in Humidifying Sample House with Liquid Desiccant Concentration of 50% and Temperature of 10 °C

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Various methods are used to control the room humidity, one of them is a dehumidification system. By utilizing a liquid desiccant such as CaCl₂, relative humidity values can be suppressed in accordance with the specified variable. Numerical simulations are used to determine the temperature distribution and relative humidity in the room using Computational Fluid Dynamics (CFD). The experiment uses a liquid desiccant concentration of 50%, temperature of 10 °C, nozzle dimension of 0.2 mm, and constant inlet air flow rate of 2.35 m³/min. Simulation results show average temperature distribution of 30.93 °C and RH of 62.80% in the room. CFD software Solidworks Flow Simulation 2014 is used for simulation.

Keywords: Dehumidification, CaCl₂, Temperature, RH, CFD.

1. INTRODUCTION
Research on the air conditioning system has been growing rapidly. There is an alternative in the air conditioning system, a system with desiccant as a working fluid. Desiccant has hygroscopic properties, which can absorb water vapor contained in the air (1).

In this research, dehumidification process using liquid desiccant are done to see the humidity drop in the sample house. With the principle of water vapor absorption in the air by liquid desiccant, dehumidification becomes one simple humidity control and energy efficient process (2). The absorption of moisture from air to absorbent occurs when the air and the solution form a contact and water vapor partial pressure conditions in the liquid desiccant are lower than in the air. As long as the partial pressure of water vapor in the air is higher, the moisture from the humid air will continue to move to the desiccant and the air humidity ratio will continue to decline until it reach steady state (3).

In this study, numerical simulation is used to determine the temperature distribution in particular flow and humidity in the room, which is impossible to be observed from experiments without using sophisticated tools such as thermal cameras. Computational Fluid Dynamics (CFD) has the ability to illustrate the airflow distribution in the room quantitatively, effectively, and accurately (4). In previous research by Catherine Baxevanou et al. (Research Paper, 2010), the same method (CFD) is used to describe the relative humidity distribution in a greenhouse. With a 3-D flow simulation model, humidity distribution in the greenhouse can be illustrated by adding a humidifier and a dehumidifier to control the humidity optimally. From these results, it can be seen that air with high humidity level tend to be in the lower level of the room because of the water vapor density. But with dehumidifier, high humidity can be controlled according to desired needs (5). In this study, CFD simulation is conducted to determine the temperature distribution and relative humidity in the sample house using a dehumidification process of CaCl₂ with 50% concentration and temperature of 10 °C. CaCl₂ is selected as liquid desiccant because it is cheaper compared to other absorbent, such as LiCl, LiBr, and Triethylene glycol (6).

2. EXPERIMENTAL DETAILS
The study is conducted by draining liquid desiccant from the tank to the dehumidifier tower. In the dehumidifier tower, CaCl₂ solution is distributed using a 0.2 mm spraying nozzle. Installation of dehumidification systems without regenerators is shown in Figure 1. Then the test data will be used as input data for the simulation with flowchart shown in Figure 2.
The following equations are used in this research.

(1) Mass Conservation

Mass balance on a fluid element can be written as follows. "The rate of mass accretion on an element is equal to net fluid mass flow rate into the fluid element."

\[
\frac{\partial \rho}{\partial t} + \text{div}(\rho \mathbf{V}) = 0
\]

(2) Momentum Conservation

Newton’s second law states that the rate of change of momentum in a fluid particle is equal to the number of forces acting on the particle.

\[
\frac{D \rho}{Dt} = \frac{\partial (\rho \mathbf{u})}{\partial t} + \frac{\partial \tau_{\mathbf{u}x}}{\partial x} + \frac{\partial \tau_{\mathbf{u}y}}{\partial y} + \frac{\partial \tau_{\mathbf{u}z}}{\partial z} + S_{\mathbf{u}};
\]
Fig. 7. Contour of air flow distribution case 2.

Table II. The comparison of 5 point between simulation and experiment.

<table>
<thead>
<tr>
<th>Censor</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
<th>Simulation Temperature (°C)</th>
<th>Experiment Temperature (°C)</th>
<th>Error (%)</th>
<th>RH (%)</th>
<th>Simulation RH (%)</th>
<th>Experiment RH (%)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.22</td>
<td>0.5</td>
<td>31.71</td>
<td>31</td>
<td>2</td>
<td>59.21</td>
<td>59</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.75</td>
<td>1.47</td>
<td>0.5</td>
<td>31.32</td>
<td>30</td>
<td>4</td>
<td>60.68</td>
<td>59</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.48</td>
<td>0.82</td>
<td>0.5</td>
<td>30.90</td>
<td>30</td>
<td>3</td>
<td>62.42</td>
<td>61</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.75</td>
<td>0.02</td>
<td>0.5</td>
<td>30.72</td>
<td>28</td>
<td>10</td>
<td>63.12</td>
<td>64</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
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<td>0.45</td>
<td>0.5</td>
<td>30.58</td>
<td>29</td>
<td>5</td>
<td>63.72</td>
<td>62</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{\rho D_u}{Dt} = \frac{\partial (-p + \tau_{xx})}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{yy}}{\partial z} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial y} + S_{Sh};
\]

\[
\frac{\rho D_w}{Dt} = \frac{\partial (-p + \tau_{xx})}{\partial z} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial y} + S_{Sh}.
\]

(3) Energy Equation

Energy equation derived from the first Law of Thermodynamics is “The rate of energy increase in a fluid particle is equal to the rate of heat addition to the fluid particle sums the work that occurs in the fluid particle.”

\[
\frac{DE}{Dt} = -\text{div}(\rho u) \left[ \frac{\partial (u \tau_{xx})}{\partial x} + \frac{\partial (u \tau_{xy})}{\partial y} + \frac{\partial (u \tau_{yx})}{\partial y} + \frac{\partial (u \tau_{yy})}{\partial z} + \frac{\partial (u \tau_{zy})}{\partial y} + \frac{\partial (u \tau_{yz})}{\partial y} + \frac{\partial (u \tau_{zz})}{\partial y} + S_{Sh} \right]
\]

\[
+ \text{div}(\kappa \text{grad} T) + S_{h}
\]

Linear Low-Density Polyethylene (LLDPE) is used to wrap a 1.5 m x 1 m sample house, the inlet and outlet are connected directly to the tower dehumidifier. Dehumidifier tower made of acrylic with a thickness of 3 mm is used in this study. Figure 3 shows the dimensions of the sample house with millimeters.

3. RESULTS AND DISCUSSION

Case 1 is a condition in which the dehumidification tower is simulated using journal initial conditions using Solidworks 2014 Flow Simulation software. The goal is to determine how well the simulation used in this experiment goes with the simulation used in the journal. From the simulation results of cases 1, validated by comparing the results of previous studies contained in the research paper Catherine Baxevanou, 2010 in the form of the simulation results of temperature in the greenhouse. Initial conditions used are as shown in Table I. By using the initial conditions as shown in Table I. The results are shown in Figure 4, the contour of temperature distributions are alike where the curve of the line is nearly resembled each other.

In the case 2, the simulation is done by running a dehumidifier to determine the air temperature distribution and RH in the sample house. From Figures 5 and 6, it is shown that the temperature distribution and RH in the room are distributed evenly around 30.93 °C and 62.80%. The highest temperature and the lowest RH occurred at the inlet (31.71 °C and 59.21%). To determine the accuracy of CFD models, validation is needed for the value of air temperature and RH of experimental results. Table II shows the comparison of 5 points between simulation and experiment. Figure 7 shows the air flow distribution profile through the inlet in the Sample House. It can be seen that the temperature distribution and RH are distributed evenly. This is because the air flows follow the shape of the Sample House room profile.

4. CONCLUSION

Modeling simulations using CFD has been proven effective to see the contours distribution of temperature and relative humidity in the room. From the simulation results, it can be concluded that the air condition in the room by turning on the dehumidifier using desiccant liquid concentration of 50% shows the temperature distribution and RH are distributed evenly at around 30.93 °C and 62.80%.

References and Notes


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